Technical Report 498

AN EXPERIMENTAL EVALUATION OF TACTICAL SYMBOL-DESIGN FEATURES

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Sixteen non-military participants learned each of two symbol sets (conventional, iconic) to a criterion. Each set contained three basic symbols representing unit types of armor, mechanized infantry, and infantry. After learning a symbol set, each participant was shown a series of situation displays, where some displays contained symbols coded with either perimeter-density or vector projection to convey supplementary unit-attribute information (unit strength or firepower reach) needed for typical tactical tasks. For each display, the

participant was asked questions corresponding to different behavioral processes (identification, search, comparison, pattern recognition). Overall, the results suggested that iconic symbols may not necessarily be preferable to conventional symbols in certain situations; and, although the portrayal of supplemental unit information can slow some aspects of information processing, certain symbol-design features appear to create less interference than others. Specifically, (a) iconic symbols did not yield faster identification performance than conventional symbols, and conventional symbols yielded faster pattern-recognition performance than iconic symbols; (b) the portrayal of supplemental unit attributes slowed processing of unit-type information in all four tasks, but vector projection created less interference than perimeter density in three of four tasks; (c) unit-strength information was processed faster when it was portrayed as perimeter density, and fire-power reach information was processed faster when portrayed as a vector projection. In a supplementary task which required integration of information from several symbols into an analytical judgment (threat value assessment), performance accuracy was found to be insensitive to the conventional versus iconic symbology comparison. The results were discussed in terms of the complexity of the implications involved in the selection of symbol design features and their correspondence with tactical concepts.

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FOREWORD

The Human Factors Technical Area of the Army Research Institute (ARI) is concerned with aiding users and operators to cope with the ever increasing complexity of the man-machine systems being designed to acquire, transmit, process, disseminate, and utilize tactical information on the battlefield. The research is focused on the interface problems and interactions within command and control centers and is concerned with such areas as topographic products and procedures, tactical symbology, user-oriented systems, information management, staff operations and procedures, sensor systems integration and utilization, and issues of system development.

The current symbology, as provided in FM 21-30 and FM 21-21, is widely agreed to be inadequate. As a result, a number of Army agencies are working to evolve special sub-sets of new or modified symbols that are better suited to their particular information-processing needs. In the absence of a common frame of reference, these efforts could result in a proliferation of specialized symbols that meet the needs of some, but not all, potential users. The present publication tries to identify and categorize the situational, information, and behavioral factors that contribute to the effective design and use of visual symbols for representing the battlefield. This analysis is a necessary first step in the development of a comprehensive framework, typology, and theory of tactical symbology.

Research in the area of tactical symbology is conducted as an in-house effort augmented through contracts with organizations selected for their specialized capabilities and unique facilities. The present study was conducted by personnel of Perceptronics, Inc., under Contract DAHC19-78-C-0018. This research is responsive to requirements of Army Project 2Q762722A765 and related to special requirements of the Combined Arms Combat Developments Activity, Fort Leavenworth, Kansas. Special requirements are contained in Human Resource Need 80-307, Optimizing Display of Topographic and Dynamic Battlefield Information, 81-57 Strategy for Design and Improvement of Communications, and 81-96 Effectiveness of Multicolor Air Defense Weapon Systems Display.

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AN EXPERIMENTAL EVALUATION OF TACTICAL SYMBOL-DESIGN FEATURES

BRIEF

Requirement:

The design of improved symbology for communicating tactical information is required in light of the complexities of the modern battlefield and increasing command and control task demands. The present study evaluated some candidate design features for tactical symbols by analyzing human performance data obtained from a series of behavioral tasks relevant to situation display usage.

Procedure:

Sixteen non-military participants learned each of two symbol sets (conventional, iconic) to a criterion. Each set contained three basic symbols representing unit types of armor, mechanized infantry, and infantry, respectively. After learning a symbol set, each participant was shown a series of tactical situation displays, where some displays contained symbols coded with either perimeter-density or vector projection to convey peripheral unit-attribute information (unit strength or firepower reach). For each display, the participant was asked a pair of questions for each of four behavioral tasks (identification, search, comparison, pattern recognition), and the speed and accuracy of responses were recorded. In addition, a fifth task (threat value assessment) required the participants to integrate several aspects of a display to derive the appropriate response.

Findings:

On the first four tasks, because of near-perfect accuracy, attention was focused on the assessment of performance speed. The following salient results were obtained: (a) iconic symbols did not yield faster identification performance than conventional symbols, and conventional symbols yielded faster pattern-recognition performance than iconic symbols; (b) the portrayal of unit attributes slowed processing of unit-type information in all four tasks, but vector projection created less interference than perimeter density in three of four tasks; (c) unit-strength information was processed faster when it was portrayed as perimeter density, and fire-power-reach information was processed faster when portrayed as a vector projection. With regard to threat value assessment, no difference in performance accuracy was found as a function of whether the conventional or iconic symbology was used.

Utilization of Findings

The findings of this experiment can guide the selection of design features for improved tactical symbology. For example, in the absence of evidence to the contrary, the present results suggest that conventional tactical symbols may be preferrable to iconic symbols (at least of the form studied--i.e., blocked, hollow iconic symbols) for use in certain tasks. Furthermore, although the number of different symbol dimensions portrayed should be kept at a minimum, some symbol-design features appear to create less perceptual interference, and have greater correspondence with specific tactical concepts, than others. However, because of the complexity of the performance effects of different symbol forms combined with peripheral features, a more extensive, generalized pool of human performance data would be desirable to insure accurate decisions about symbol designs.

AN EXPERIMENTAL EVALUATION OF TACTICAL SYMBOL-DESIGN FEATURES

CONTENTS

FIGURES

INTRODUCTION

Emerging doctrine and advancing technology call for the development of improved tactical symbology, and considerable effort is being directed toward that goal (e.g., Ciccone, Samet, and Channon, 1969; Sidorsky, Gellman, and Moses, 1979). For example, military analysts are focusing attention on the need to include the graphic portrayal of such key concepts as the dynamic composition of units and unit capability (strength, reach, mobility, etc.) in tactical situation displays (e.g., Middleton, 1977; Sidorsky, 1977). At the same time, innovations in computer graphic hardware and software have enabled the cost-effective application of creative symbol-design features such as iconicity, variable density, flashing, color, vector projection, etc. Thus, a major problem in symbology development involves the identification of promising design features that exploit the capabilities of automated displays in a manner that can best serve the information requirements and task demands of tactical users.

The impact of future symbology on tactical decision making will depend largely on the extent to which the symbology can be perceived and interpreted by the user (e.g., see Biberman, 1973). Unfortunately, however, our knowledge of the human factors principles underlying effective symbol design is rather limited. In particular, more empirical data are required that can be utilized to generate guidelines for the design of symbols. Since the same military symbols are typically used across an entire range of display configurations and tactical tasks, the derivation of generalized principles of effective symbol design is a challenging area of research.

In order to bridge the conceptual gap between the design of tactical symbols and their use in actual tasks, we have adopted the premise that

any such task can be cataloged or decomposed according to perceptual-cognitive processes or functions required for successful task performance (cf, Fleishman, 1975). For example, the task of viewing a situation display and determining whether a group of specific enemy units is in an attack formation might require the operation of behavioral processes related to identifying these units, finding their locations, matching their formation with that of a given template, etc. Because of this relationship between tactical tasks and basic behavioral processes, which in turn are affected by physical features of symbol designs, the evaluation of the effects of symbol characteristics on these processes provides useful human-performance data. Such data then become part of the reservoir of knowledge needed to establish sound principles for effective symbol design.

Hence, as part of a systematic approach to the investigation of candidate symbol-design features, a taxonomy of typically required behavioral symbol-use processes has been defined and is presented in Table 1. Not meant to be an end in itself, the taxonomy is intended to provide a framework for aiding the planning of research studies, and the interpretation and organization of empirical findings. Although there is probably no such thing as a "best" categorization, the suggested structure is viewed by the authors as logical, coherent, and useful. The taxonomy treats the utilization of symbols, in general, as a multi-level endeavor involving the processing of individual and multiple symbols. The list of behavioral processes begins with symbology acquisition (learning) and then spans the entire range of symbol-use activities from detection and identification of single symbols to the interpretation and integration of a configuration of several symbols. The processes, as defined in the taxonomy, are by no means independent since certain higher-level operations are composed of a combination of lower-level operations--for example, counting involves detection, identification and search.

TABLE 1

TAXONOMY OF SYMBOL-USE PROCESSES

Symbology Acquisition

Perceptual Learning - acquisition of a code necessary for future recognition of a form.

Association - acquisition of a mental link between a form and the concept that it portrays.

Processing Individual Symbols

Detection - acknowledgement of the presence of a form.

Identification - interpretation of a detected form.

Search - determination of the location of an identified form.

Tracking - sustained detection of a mobile form.

Updating - acknowledgement of an alteration of a form.

Processing Multiple Symbols

Comparison - acknowledgement of sameness and/or differences among two or more identified forms.

Counting - keeping track of the number of instances that a given form is encountered.

Pattern Recognition - interpretation of the spatial arrangement of two or more identified forms.

Integration - combination of information from two or more identified forms toward a simplified characterization of the set of forms.

Ideally, tactical symbols should be designed to enhance rather than to inhibit human performance in symbol-processing tasks. The efficacy of symbol-design features might therefore be assessed in terms of how they affect performance along the fundamental task-related dimensions belonging to the taxonomy in Table 1. For the purposes of the present research, emphasis was placed on behavior related to the processing rather than the acquisition (learning) of symbols--the latter being addressed elsewhere (e.g., Bersh, Moses, and Maisano, 1978). Five behavioral processes were selected for investigation. These processes, assumed to be essential in the use of symbols for the accomplishment of actual tactical planning and/or decision making tasks, were operationally defined as follows: (a) identification--naming of symbolic information appearing in a specified display location; (b) search--enumerating display locations containing a particular type of symbol; (c) comparison --acknowledging sameness between one displayed symbol and others; (d) pattern recognition--locating an attack pattern (wedge formation) of symbols embedded in a display; and (e) integration--analytical assessment of the overall threat value of units in certain sectors of a display based upon multiple symbol features. Each of these performance dimensions was treated in the experimental design as a separate component for analysis.

Given the framework of symbol-use processes as a vehicle for studying related task performance, the next step in demonstrating a systematic evaluation methodology was to identify a set of symbol design features that are worthy of exploration. These features are graphic characteristics of symbols, defined in physical terms, which appear to have an impact on user symbol-processing performance. Analyses of the results and implications of empirical studies that are relevant to the evaluation and design of symbol features are available elsewhere (see Ciccone, et al., 1979; Geiselman, Landee, and Samet, 1979; Hemingway, Kubala, and

Chastain, 1978). For the present experiment, three different symbol-design features were selected for investigation: iconicity, perimeter density, and vector projection. Iconicity (i.e., the degree to which a symbol looks like its referent) relates to a symbol's basic internal form or shape; perimeter density and vector projection, on the other hand, can be thought of as peripheral attributes of symbols.

The rationale for the development of iconic symbols is based on their hypothesized ease of learning and increased associability with the concept they are designed to represent (e.g., Machover, 1977). By allowing for "natural" associations (Bersh, et al., 1978), the imageability of a symbol, or the ease with which an accurate mental image of its visual form can be generated, is likely to be enhanced. In other words, the iconic symbol, in looking like what is already familiar to the user, should strengthen assocation formation by taking advantage of the user's prior learning and conditioning (Foley and Wallace, 1974); the plausibility of this contention with regard to military symbols has received both theoretical (Middleton, 1977) and empirical (Hemingway, et al., 1978) support. Furthermore, because well-learned iconic symbols generally offer the user a large number of discriminating visual cues, their perceptibility and interpretation may be less affected by degraded viewing conditions such as reductions in symbol size or illumination (Howell and Fuchs, 1961; Shurtleff, 1974). On the other hand, the added physical complexity of iconic symbols could, conceivably, decrease learnability (Attneave, 1957) and might increase display clutter (Hemingway, et al. 1978), consequently leading to performance decrements in certain tasks. Overall, it is difficult to formulate a clear-cut hypothesis about the effects on symbol-processing performance of iconicity and its interaction with other design features.

Symbol iconicity can range from photograhic reproduction to abstract approximation. For example, the detailed "tank" symbol presented at the top of Figure 1 probably contains more information than is required for efficient and accurate recognition. The detailed silhouette design on the left-hand side of the figure contains fewer visual cues but seems sufficient to insure rapid recognition. An even simpler iconic approximation is the "blocked" design on the right-hand side; each blocked figure shown was drawn using a 12 x 28 matrix of small squares. Because the blocked iconic symbol carries the advantage of relative compatibility with an automated display system, it was selected for analysis in the present experiment. Furthermore, the outline blocked iconic symbol was chosen because of the suggestion that simple silhouettes, as opposed to more detailed forms, may facilitate the speed and accuracy of recognition performance (Chainova, Komarova, and Zonabend, 1974; Yoeli and Loon, 1972) and because the comparison symbol employed in the experiment (i.e., conventional military symbol) is also composed, more often than not, of hollow outlines.

The remaining symbol-design features investigated here are extraneous to the fundamental form of the symbol. Such peripheral design features have been advocated for the purpose of conveying supplementary information about a given referent. So, for example, if the referent is an armor unit, an appended feature might be designed to represent the unit's threat value (Moses, 1977), combat effectiveness (Middleton, 1977), strength or reach (Channon, 1978), or some other aspect of tactical capability (Sidorsky, 1977). In addition, specific designs for communicating such attributes about units have been suggested in the literature (e.g., the doughnut symbol proposed by Sidorsky, 1977). For the present work, two peripheral design features were selected for investigation--namely "perimeter density" and "vector projection." Perimeter density coding has been described by Middleton (1977) as a modification to con-

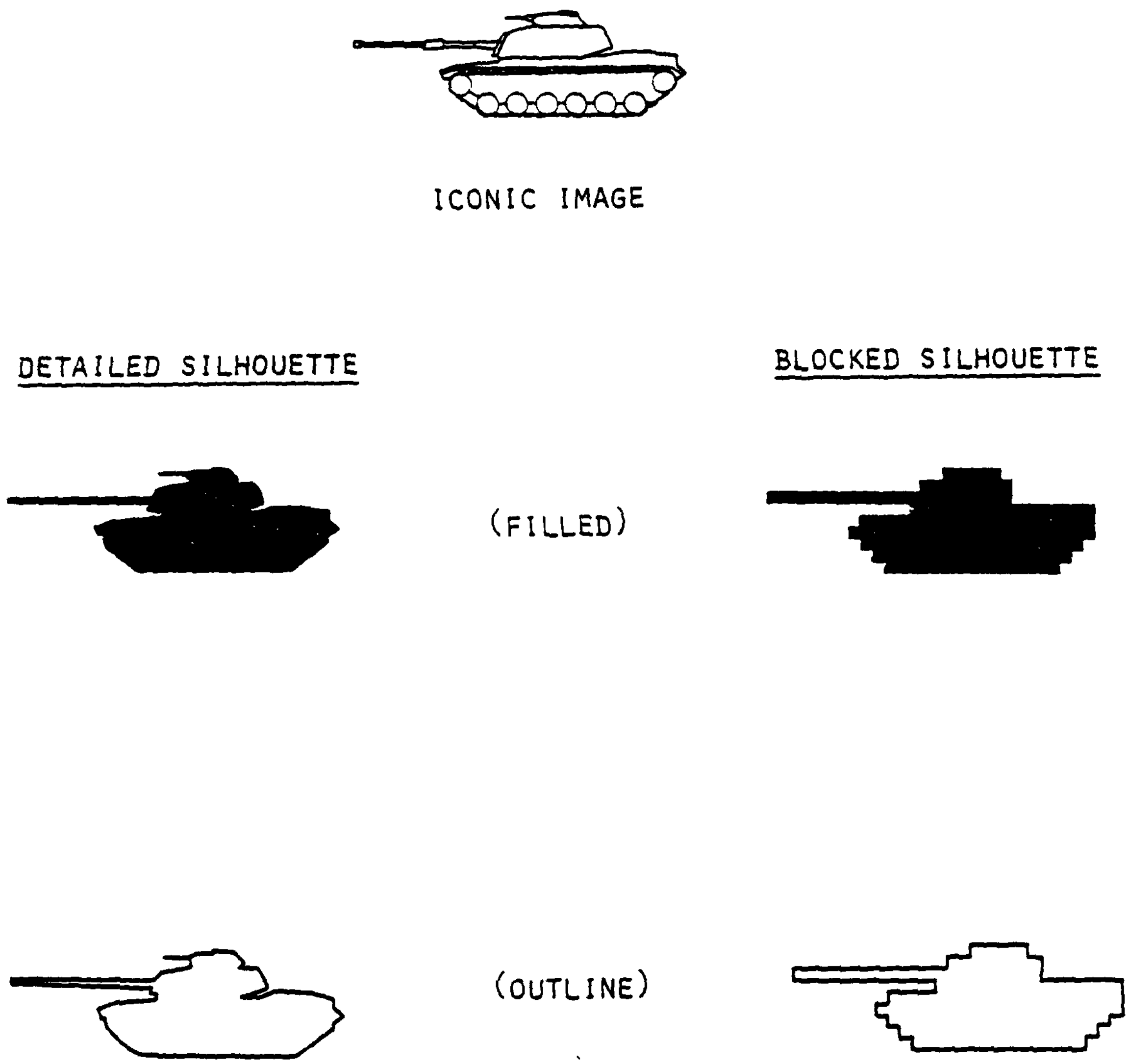

FIGURE 1. ICONIC SYMBOLS FOR ARMOR

ventional symbology in order to portray combat effectiveness. Different levels of percent combat strength can be represented by proportionally shading the double box (perimeter) surrounding a conventional (FM 21-30) symbol. Vector projection, in contrast, has been put forth as a design feature that emanates from a symbol in a manner that might convey information about the direction and distance of a given unit's firepower reach (Channon, 1976). Perimeter density and vector projection were thus offered as symbol design features for portraying specific attributes of unit symbols. However, as will be demonstrated by the experimental design, perimeter density and vector projection can theoretically be combined with either conventional or iconic symbols.

In sum, the objective of the present research was to assess the impact of some candidate symbol-design features on user performance in basic symbol-processing tasks. Three symbol-design features (iconicity, perimeter density, and vector projection) were selected for investigation, and the effectivenss of each feature was evaluated by examining its influence on both the speed and accuracy of performance with respect to five behavioral processes (identification, search, comparison, pattern recognition and integration). Performance on each process was measured by responses to simple questions about symbols appearing on simulated battlefield displays. These displays were constructed and employed so that the symbol design features could be evaluated in a realistic symbol configuration rather than in isolation. Furthermore, the experimental design allowed for the determination of whether one symbol-design feature is better suited for satisfying one behavioral process (e.g., identification), whereas another symbol-design feature might be better suited for satisfying a different behavioral process (e.g., pattern recognition).

In addition to the investigation of direct effects of the various symbol-design features on processing performance, an assessment was made of the indirect effects of displaying a given symbol-design feature not needed for task performance. For example, consider how the use of vector projection to specify some supplementary military concept might affect performance on the identification of unit type (as portrayed by a conventional or iconic symbol). Although such extraneous information is irrelevant to unit identification, its presence can increase display clutter or cause interactions which decrease performance on the primary task. One other research concern was to determine which pairing of the military concepts (unit strength, firepower reach) with the attribute symbol-design features (perimeter density, vector projection) is more effective. Overall, such considerations were viewed as important in arriving at conclusions about the potential effectiveness of each symbol-design feature.

METHOD

Participants

The participants were 16 non-military individuals between the ages of 20 and 30, 8 males and 8 females. Each received a flat rate of $4.00 for the experimental session which lasted about 1.5 hours. In addition, a bonus of up to another $3.00 was provided which they were instructed would depend upon the speed and accuracy of performance. Each participant was tested individually by the same experimenter, and the sex of the participants was counterbalanced across the one between-participants factor in the design.

Materials

Thirty-six tactical battlefield displays were generated for use in the experiment. Samples of these displays are presented in Figures 2, 3, 4, and 5. A dark line down the center of each display represented the line on the battlefield said to separate the friendly and enemy forces (the "battlefield line"). The friendly forces always were portrayed on the left side of the battlefield; and the enemy forces always were shown on the right side. The vertical-by-horizontal dimensions of each display were 9 x 14 inches, and this area was marked off into 126 small squares. These squares were labeled with the letters A-N horizontally and with the numbers 1-9 vertically. Thus, each square could be identified by a letter and a number, such as square C-4, or square A-2. The battlefield as a whole was divided into three major sectors from top to bottom: the Northern sector (rows 1, 2, and 3), the Central sector (rows 4, 5, and 6), and the Southern sector (rows 7, 8, and 9).

The friendly and enemy forces were composed of three basic types of units: armor, mechanized infantry, and infantry. No more than one unit was portrayed in any given square on a display, and the friendly and enemy forces always contained 30 units each. In total, six different scenarios (configurations of units) were constructed, with six different versions of each scenario. Three versions were prepared using the conventional symbols (FM 21-30) for the three types of units used, and the remaining three versions were prepared using blocked iconic symbols. Examples of displays with conventional symbols are shown in Figures 2 and 3, and displays with iconic symbols are shown in Figures 4 and 5; note that the iconic symbols for the friendly and enemy forces are rotated so that they oppose each other.

For each type of symbology, two versions of each scenario included the portrayal of one symbol-design feature (perimeter density as in Figure 3, or vector projection as in Figure 5), which represented certain supplementary tactical information (unit strength or firepower reach) about each unit. As outlined below, the pairing of military concepts with symbol-design features was counterbalanced across participants and was not confounded with the military concepts. A third version of each scenario did not include the portrayal of tactical information beyond unit type, as in Figures 2 and 5. Thus, the 36 displays were generated from 6 different scenarios, 2 types of symbology (iconic or conventional), and 3 levels of a symbol design feature (perimeter density, vector projection, or no feature portrayed).

When a symbol-design feature was included in a display, three levels of the feature were used representing (a) 100% strength or 60 KM firepower reach, (b) 50% strength or 40 KM reach, and (c) 0% strength or 20 KM reach. Three corresponding levels of perimeter-density were: all four sides blackened in, two sides blackened in, or no sides blackened in (see Figure 3). The vector projection consisted of four small circles emanating from the side of the symbol closest to the center of the display. Three vector projection levels were: all four circles blackened in, two circles blackened in, or no circles blackened in (see Figure 5).

In a given display, one or two contrived configurations of units were embedded within each set of forces. The general pattern that was embedded was referred to as an "attack" formation--a wedge shape, composed of seven units, pointed toward the battlefield line. One wedge shape within each set of forces in every display was composed of all armor units. (The vertex, or lead armor unit, of a wedge is located in squares F-5 and J-5 in Figure 2, F-4 and I-6 in Figure 3, F-4 and K-4 in

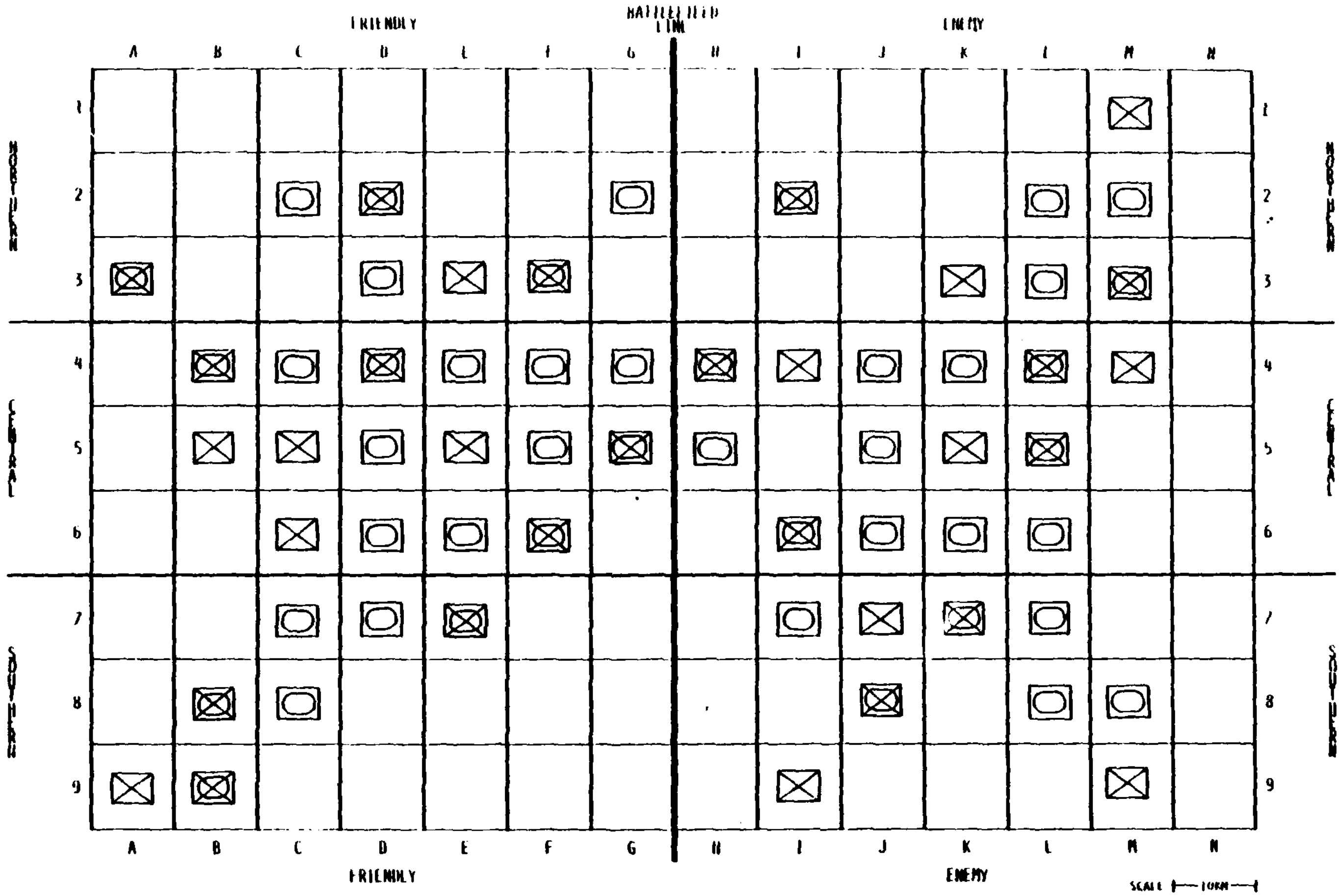

FIGURE 2. CONVENTIONAL SYMBOLS

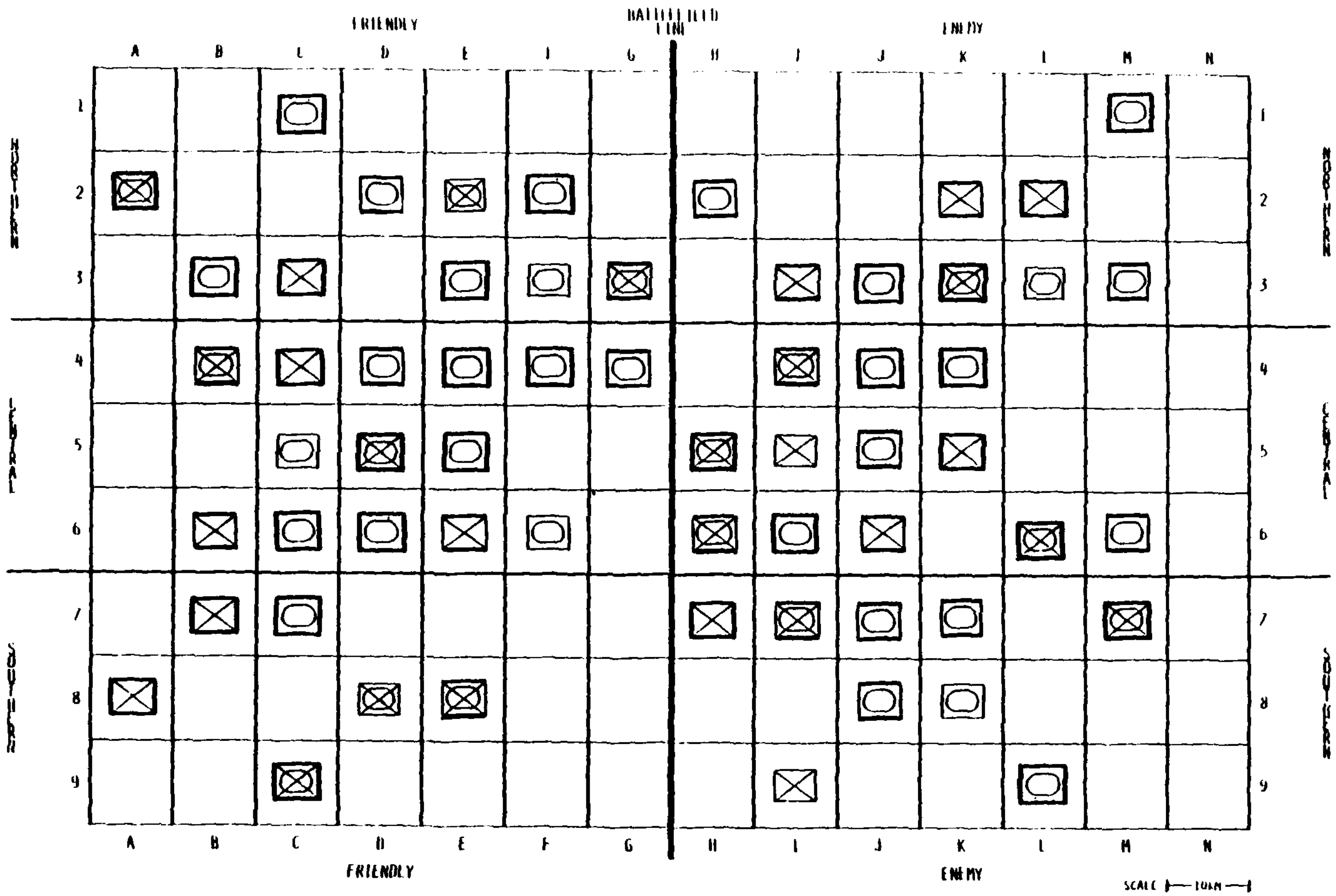

FIGURE 3. MODIFIED CONVENTIONAL SYMBOLS WITH PERIMETER DENSITY FEATURE

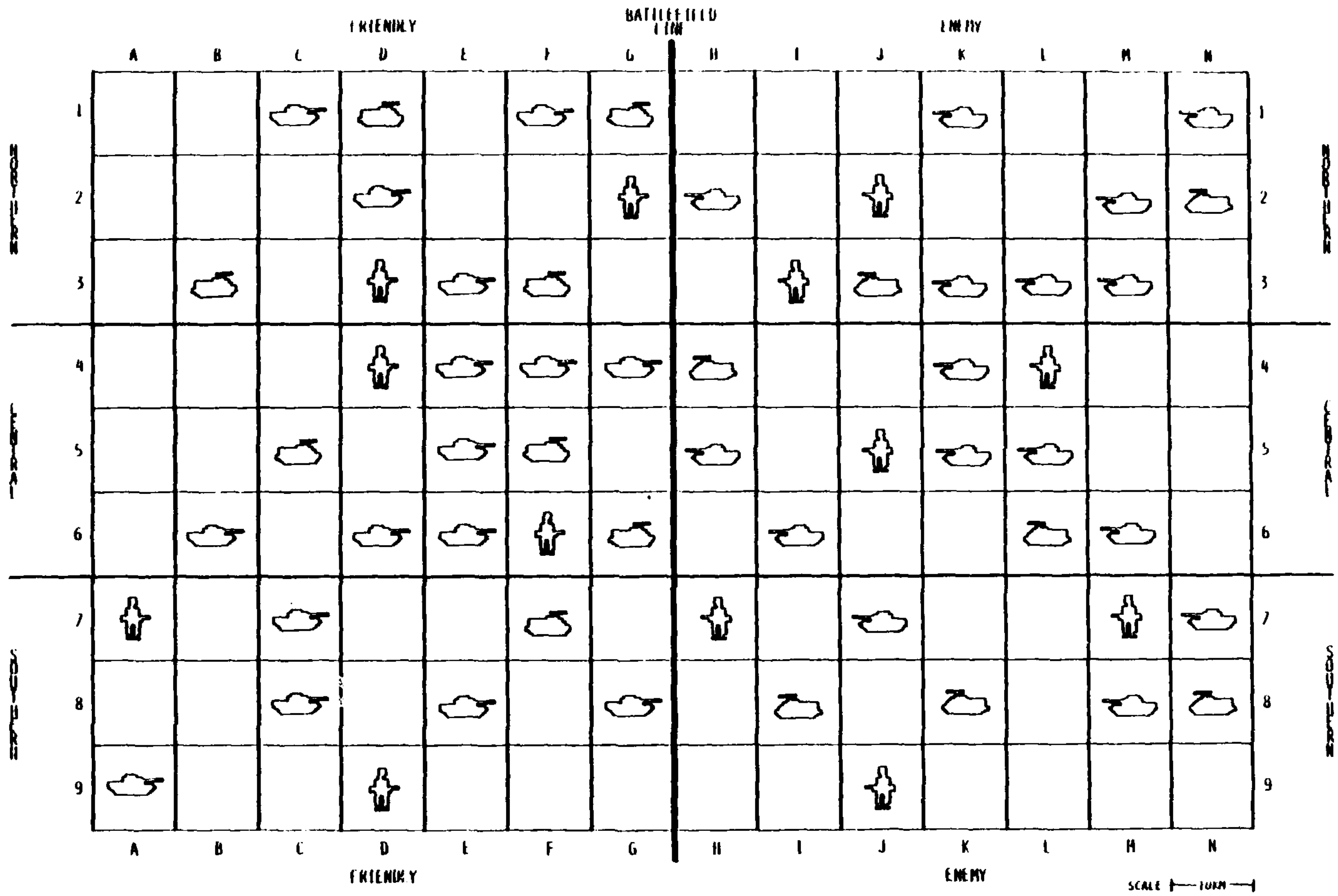

FIGURE 4. BLOCKED ICONIC SYMBOLS

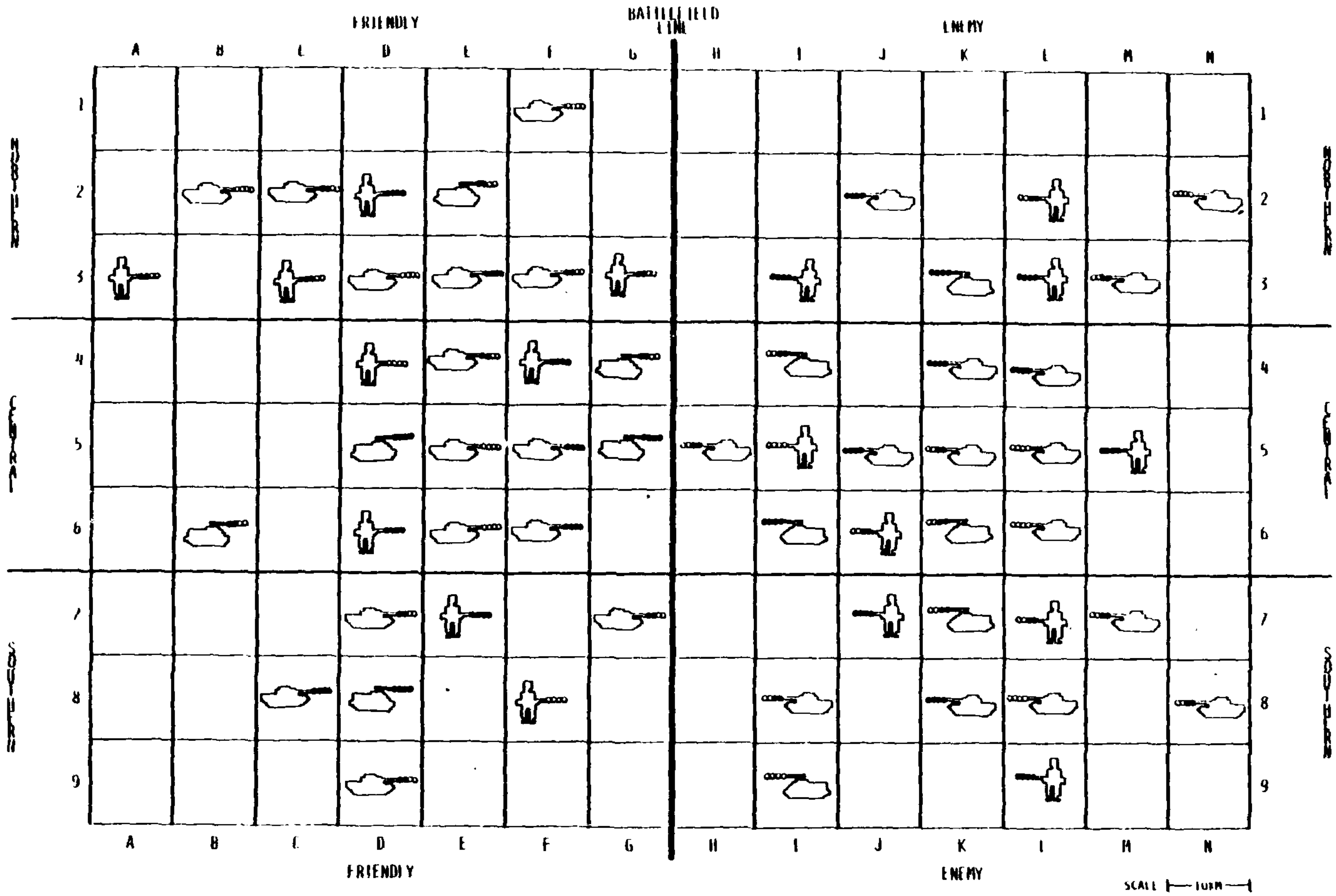

FIGURE 5. BLOCKED ICONIC SYMBOLS WITH VECTOR PROJECTION FEATURE

Figure 4, and F-5 and K-5 in Figure 5.) In addition, for displays that included perimeter-density or vector projection, a second wedge shape within each set of forces was specified by seven unit symbols (of mixed unit types, i.e., infantry, mechanized infantry, and armor) with full density coding (e.g., see vertex at D-5 and J-4 in Figure 3) or fully-blackened vector projections (e.g., see vertex at G-5 and I-6 in Figure 5), respectively. These patterns were the basis for questions regarding spatial pattern recognition.

Procedure

The general layout of the experimental design for a single participant is illustrated in Figure 6. The procedure was divided, first of all, on the basis of the symbology factor (conventional or iconic symbols). The order in which the two levels of the symbology factor was presented was counterbalanced across participants. All data pertaining to one of these symbol sets, except data from the integration task, were collected before the other set was learned; and a sample booklet used to teach the participants one of the sets is presented in Appendix A. Also, a pretest was given to each participant before proceeding with each half of the experiment to insure that each symbol set was mastered to an acceptable level. (A sample pretest is presented in Appendic B.) Each participant was required to be able to complete this pretest within three minutes and with no more than two errors before continuing with the experiment. These cutoffs were chosen on the basis of a brief pilot study and represent the 75th percentiles of the pilot participants' performance on the time and accuracy dependent variables.

The procedure was divided, second of all, on the basis of the type of behavioral task (identification, search, comparison, spatial pattern recognition, and integration); the order of presentation of the first

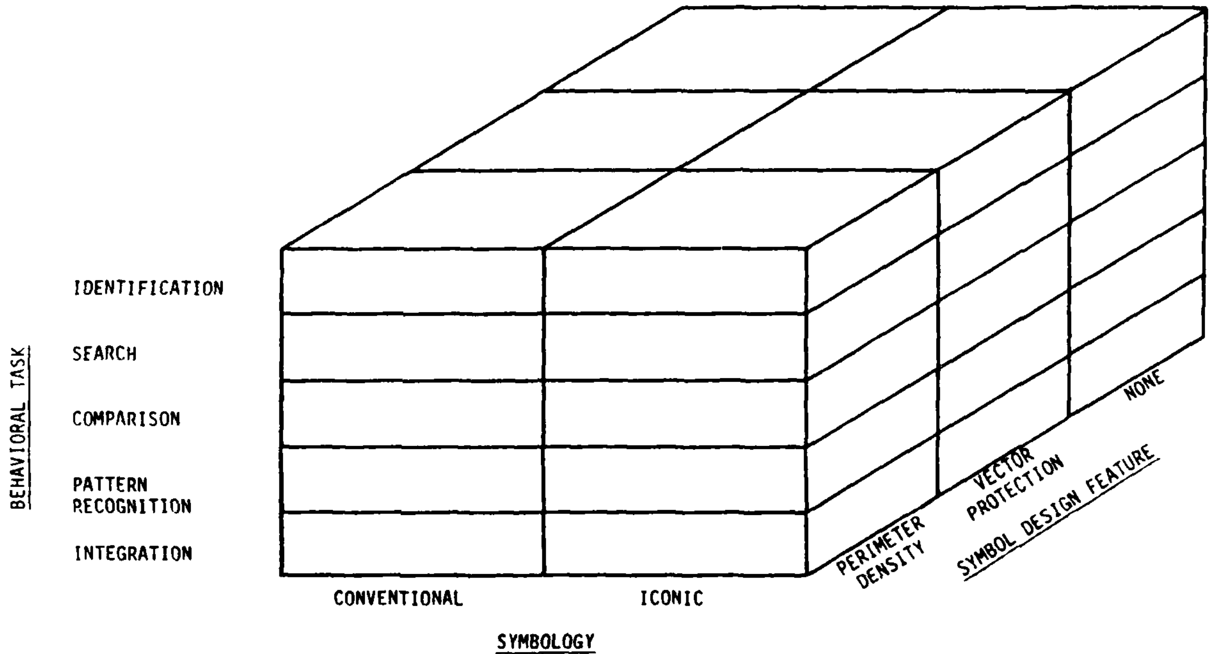

FIGURE 6.
EXPERIMENTAL DESIGN

four tasks was counterbalanced across participants, but the integration (threat-value assessment) task was always done last because of the extensive instruction that was necessary to enable a participant to perform that task.

Within each of the ten experimental segments created from the combination of the symbology and behavioral task factors, three displays were presented on paper, one at a time: One included the perimeter density symbol-design feature, one the vector projection feature, and one included neither of these features. The same three displays were presented in sequence for the identification, search, comparison, pattern-recognition, and integration tasks within each level of the symbology factor. Half of the participants learned each of the two design-feature by military-concept combinations (perimeter density = unit strength, vector projection = firepower reach; or vice versa). Thus, the only between-participants factor in the design was the feature-concept combination factor.

For each behavioral task except integration (threat-value assessment), a total of ten questions were asked. The procedure for the integration task is described separately later. In each of the other four tasks, a pair of questions was asked for each display that referred to unit type (armor, mechanized infantry, or infantry); and for those displays that included an attribute symbol-design feature (perimeter density coding, vector projection), an additional pair of questions was asked that referred to the military concept associated with that feature (unit strength or firepower reach). The experimenter recorded the participant's verbal responses to the questions and also recorded the total time (using a stop watch) that a participant took to answer a pair of questions. The reaction time in answering a single question was taken as the interval between the experimenter's completion of reading the

question and the participant's completion of answering the question. This time was summed for the two questions in a pair. Examples of these questions (and the figure referred to by each) are as follows:

Identification

(1) Unit Type: In square J-3, what is the name of the unit? (Figure 3.)

(2) Strength: In square D-8, what is the percent strength of the unit? (Figure 3.)

(3) Reach: In square K-7, what is the kilometer reach of the unit? (Figure 5.)

Search

(1) Unit Type: In the central sector of the enemy side, name all of the squares that contain infantry units. (Figure 2.)

(2) Strength: In the northern sector of the friendly side, name all of the squares that contain units with 100 percent strength. (Figure 3.)

(3) Reach: In the southern sector of the enemy side, name all of the squares that contain units with 20 kilometer reach. (Figure 5.)

Comparison

(1) Unit Type: On the friendly side in row 4, name all the squares that contain the same type of unit as in J-4. (Figure 2.)

(2) Strength: On the enemy side in row 5, name all the squares that contain a unit that has a greater strength than the unit in C-5. (Figure 3.)

(3) Reach: On the friendly side in row 2, name all the squares that contain a unit that has a greater reach than the unit in H-5. (Figure 5.)

Pattern Recognition

For these questions, the participants were first read the following instructions:

> "I will now ask you to find attack patterns. You will be told which side (enemy, friendly) of the map to look on and how the wedge has been formed that you are to find (all armor units, all units at 100% strength, all units with 60KM reach). In identifying the location of an attack wedge, you simply name the square containing the unit that is at the point (vertex) of the wedge pattern. That is, you are to give the letter-number designation for the lead unit's location on the map, such as H-6."

(1) Unit Type: For the friendly side, identify the attack pattern composed of armor units. (Figure 2.)

(2) Strength: For the enemy side, identify the attack pattern composed of units at 100% strength. (Figure 3.)

(3) Reach: For the friendly side, identify the attack pattern composed of units with 60 KM reach. (Figure 5.)

To insure that the participant understood what response was expected for each type of question, feedback was given on the first occurrence of each type of question. This feedback included information concerning the accuracy of the participant's responses and the rationale for the correct answers when errors were made.

Integration

In a final part of the experiment, each participant again was shown a series of six battlefield displays, corresponding to the six displays shown during the first part of the experiment. This time, the participant was asked to compare the "threat value" of the other groups of military units also shown in the display. The threat value of a group of units was said to be determined jointly by four factors:

(1) The total number of units in the group.

(2) The type of units (armor units have greater threat value than mechanized infantry units which in turn have greater threat value than infantry units).

(3) The distance of the units from the battlefield line separating the enemy from the friendly units (units closer to this line have greater threat value).

(4) The percent strength or firepower reach of the units (the greater the strength or reach, the greater the threat value).

For each display, the participants were asked three types of questions in a fixed order. First, they were asked which of the four corner sectors (that is, the Northern and Southern sectors on both the friendly and enemy sides--thus omitting the two central sectors) had the greatest threat value. Second, they were asked which of the four corner sectors had the least threat value. Third, they were asked which side (enemy or friendly) had the greatest threat value overall. For this third question, all three sectors (the Northern, Central, and Southern) on a given side were to be considered as a block for comparison with the combined three sectors on the other side.

The participants were told that they would not be given enough time to compute the threat value in any comprehensive or time-consuming manner.

> "For each question, you will be required to compare sectors in an overall way and to make an estimate after only 20 seconds. Do not try to count the number of units in a sector since you won't have time and also because number alone does not determine threat value; i.e., unit type, closeness to battlefield line, and strength and reach also play a role.

One practice trial (using a practice display) was given with feedback before this phase of the experiment was begun.

Design and Analysis

The analysis of the data collected during the first part of the experiment, which excludes the integration (threat-value assessment) task, was divided into two major segments, one concerning the questions referring to unit type, and one concerning the questions referring to unit attributes (unit strength and firepower reach as portrayed by the two symbol-design features). Within each of these two segments, four analyses were conducted, one corresponding to each of four tasks (identification, search, comparison, pattern recognition). Thus, eight analyses were performed in all. Each analysis consisted of an analysis of covariance on the log reaction-time data using the accuracy data as a covariate. The analysis of covariance was used to partial-out the effects of any speed-accuracy trade-off from the reaction-time data as a standard normalization procedure for such measures.

The design for each of the analyses concerning questions pertaining to unit type is as follows: 2 (Symbology: conventional symbols, iconic symbols) x 3 (Symbol Design Feature: perimeter density, vector projection, none) x 2 (Combination of symbol design feature with military concept: density = strength, vector = reach; or vice versa). The feature-concept combination factor was the only between-participants factor. The design for the analysis concerning questions pertaining to the unit attributes (strength, reach) was identical to the above design. However, because questions regarding unit attributes could not be asked when such attributes were not portrayed, the factor of Symbol-Design Feature had only two levels (perimeter density and vector projection).

The design for the analysis of the accuracy data collected during the final portion of the experiment concerning threat-value assessment was

as follows: 2 (Symbology: conventional symbols, iconic symbols) x 3 (Symbol Design Feature: perimeter density, vector projection, none) x 2 (Combination of symbol design feature with military concept). The dependent variable was the percentage of correct responses on the three threat assessment questions; since a fixed time (20 seconds) was provided for each response, reaction time was not meaningful for this task.

For purposes of scoring the participant's responses in the threat value assessment task, arbitrary linear weights were assigned to each threat dimension. The threat-value for each sector in each display was then computed as follows:

$$\text{Threat Value} = \sum_{i=1}^{n} T_i \times D_i \times A_i$$

where for each of the n symbols present in the sector, T refers to the threat-value weight for the type of unit (armor = 3, mechanized infantry = 2, and infantry = 1), D refers to the weight for the distance from the battlefield line (each of the two squares closest to the battlefield line = 3; the third, fourth, or fifth squares away from the battlefield line = 2; and each of the two squares farthest from the battlefield line = 1), and A* refers to the weight for the unit attribute portrayed (100 percent strength or 60KM reach = 3, 50 percent strength or 40KM reach = 2, and zero percent strength or 20KM reach = 1). The attribute weight (A) is included in the equation only for displays that contain the portrayal of unit-attribute information (percent strength or firepower reach). As an example, in Figure 3, the corner sector with the largest

*When no unit attribute was portrayed, A was omitted from the computational formula.

threat value is the upper left-hand corner (threat value = 118); whereas the corner sector with the lowest threat value is the lower left-hand corner (threat value = 48). In this display, the enemy side has the greater overall threat value (enemy = 329, friendly = 326).

RESULTS

The eight analyses of the accuracy data for the unit-type and unit-attribute questions in the identification, search, comparison, and pattern-recognition tasks showed no significant effects. For these tasks, 96% of all responses were correct. Thus, attention is directed toward the reaction-time data for those tasks.

Iconic Versus Conventional Symbology

Only two of the eight analyses of the reaction-time data showed significant effects involving the symbology factor, and both of these analyses concerned the pattern-recognition task. First, participants were able to find "attack" patterns based on unit type (all armor units) faster when conventional symbols were used than when iconic symbols were used (6.15 sec versus 8.06 sec, $\underline{F}(1, 13) = 4.32$, $\underline{p} < .04$). Second, participants were able to find "attack" patterns based on unit attributes (all 100% strength or all 60KM reach) faster when conventional symbols were used than when iconic symbols were used (5.68 sec versus 7.08 sec, $\underline{F}(1, 13) = 5.50$, $\underline{p} < .04$), except when vector projections were used to portray reach. It is not immediately clear why the latter condition should have produced deviant results. In general, however, certain patterns of symbols can be located faster in a display of the type studied if conventional symbols are used. In addition, neither units themselves nor unit attributes were easier to identify (name) when iconic symbols were used (unit-type questions, $\underline{F} < 1$; unit-attribute questions, $\underline{F}(1, 13) =$

2.64, $p > .05$). An advantage for iconic symbols could not have been offset by prior exposure to conventional symbols because the present participants were non-military individuals with little or no prior exposure to the conventional symbols. In addition, each symbology was learned to a strict criterion in this experiment.

Symbol-Design Features

The portrayal of unit attributes in the displays was found to slow the reaction time in all four of the task analyses concerning questions about unit-type information. The main effects of design feature in the four analyses were as follows: Identification, $F(2, 27) = 25.6$, $p < .001$; Search, $F(2, 27) = 4.07$, $p < .03$; Comparison, $F(2, 27) = 27.1$, $p < .001$; and Pattern Recognition, $F(2, 27) = 25.2$, $p < .001$). However, in three of these four tasks (identification, comparison, pattern recognition), the portrayal of an attribute by perimenter density coding slowed reaction times more than did the use of vector projection. These results are shown in Table 2. (Tukey's HSD post-tests were applied to each of the main effects of design feature with a significance level of $p < .05$ adopted for all comparisons.) Thus, even though both design features interfere with the processing of unit-type information to some extent, the vector-projection feature slows down the extraction of unit-type information from a display less than does the perimeter-display feature. The perimeter-density design feature was also found to yield slower reaction times than the vector design feature for unit attribute questions, but only in the comparison task, $F(1, 13) = 4.26$, $p < .05$.

TABLE 2

MEAN REACTION TIME FOR ANSWERING PAIRS OF UNIT-TYPE QUESTIONS (IN SECONDS)

TASK	DESIGN FEATURE				
	PERIMETER DENSITY		VECTOR PROJECTION		NONE
Identification	5.21	>	3.86	>	3.10
Search	14.45	=	14.73	>	11.47
Comparison	14.30	>	11.82	>	8.50
Pattern Recognition	19.30	>	14.44	>	10.07

Note: All indicated differences were significant at $\underline{p} < .05$.

Combination of Military Concepts with Design Features

The processing of unit attribute information, under certain condtions was found to be faster when perimeter density was used to portray unit strength and vectors were used to portray unit reach, as compared to when the reverse combination was used. With the search task, the Design-Feature x Combination interaction effect was significant, $F(1, 13) = 5.4$, $p < .04$. Performance in processing unit-attribute information was faster when perimeter density was used to portray unit strength rather than reach (6.03 sec versus 8.73 sec), but performance did not differ as a function of which military concept was associated with the vector-projection design feature. The Symbology x Design x Combination interaction effect was significant, $F(1, 13) = 5.5$, $p < .04$. Performance in locating the "attack" patterns based upon unit-attribute information was faster when perimeter density was used to portray unit strength, regardless of the symbology used (5.57 sec versus 6.94 sec); but processing was faster when vector projection was used to portray unit reach, though only when iconic symbols were used. It is not clear why the "density = strength, vector = reach" combination produced faster reaction times only in these specific conditions; but since the reverse combination did not produce significantly faster performance under any of the conditions studied, it is probably the case that certain design features are more suitable to portray certain unit attributes than others.

Threat Value Assessment

In spite of the apparent difficulty of the threat-value assessment task, the average percentage of correct responses was 73.7%, in contrast to a 33.3% chance level. It is of interest that these evaluations of the complex displays were not affected by the type of symbology used

($F < 1$). Thus, the iconic symbols used here did not facilitate the summarization or integration of the symbolic information displayed. This result is consistent with the findings that neither the identification, search, comparison, nor pattern recognition tasks were performed more quickly with iconic symbols.

The only significant source of variation in the threat-value assessment data was the main effect of symbol design feature, $F(2, 14) = 3.79$, $p < .05$. A Tukey's test showed that the assessment of overall threat was more accurate when no design features were portrayed. The mean percentage of correct responses (out of three) was 72.0% for perimeter density, 64.6% for vector projection, and 84.3% when neither symbol design feature was used. Thus, when one less factor was figured into the symbol integration task, performance was significantly better. However, whether this improvement resulted from the reduction in perceptual characteristics (symbol design features) or from the simplified analytical assessment (computation) cannot be determined from the present data.

DISCUSSION

Iconic Versus Conventional Symbols

The results of this experiment illustrated that iconic symbols did not facilitate human performance over conventional (FM 21-30) symbols for the range of symbol-use tasks that were studied. In each of the comparisons made here, either no differences in performance were obtained as a function of conventional versus iconic symbology or the conventional symbols were found to yield superior performance. When the participant's task was to locate a specified pattern of symbols in a display, reaction times were shorter with conventional symbols than

with iconic symbols. One explanation of this result is that the iconic symbols used here were more complex than their conventional counterparts, where complexity is defined by the number of different lines and angles present in the symbol (Attneave and Arnoult, 1966). Such complexity might impair pattern recognition by reducing the discriminability of symbol-design features (Estes, 1972). In this regard, Hemingway, et al., (1978) have suggested that iconic symbols "create more clutter than most existing symbologies," especially when many symbols are displayed simultaneously.

The complexity of iconic symbols, however, might be shown to shorten reaction times if the symbols in a display were allowed to overlap considerably, as would be necessary if superimposed symbols were used to portray combined arms forces. This is because the well-learned features of the iconic symbols would serve as discriminative cues (cf. LaBerge, 1976); whereas with super-imposed conventional symbols, the identity of the component shapes might be obscured. In the present experiment, this possibility could not be tested since no two symbols were allowed to overlap.

It is surprising that identification (naming) performance was not found to be faster with iconic symbols, particularly in light of previous research findings that iconic symbols are ranked as more meaningful than conventional symbols (Hemingway, et al., 1978) and that iconic symbols are recognized with fewer errors under degraded viewing conditions (Howell and Fuchs, 1961). However, the participants used in the present experiment, although unfamiliar with conventional symbology were able to learn these seemingly less meaningful images and manipulate them both visually and mentally as fast as they could perform these same operations with iconic symbols. One explanation for this result is that only three different types of units were used in the present experiment.

Perhaps with a far greater number of different symbols (as required in processing information from actual tactical displays), the iconicity variable would play a more important role. Another explanation is that two of the iconic symbols (armor and mechanized infantry) were highly similar, and that this led to slowed overall processing times for the iconic symbol set. In this regard, a high degree of feature redundancy among members of a symbol set has been found to impair discrimination in terms of response latency (Bjork and Murray, 1977; Egeth, 1966). However, a similar case could be made for the conventional symbols since the armor and infantry symbols combine geometrically to yield the symbol for mechanized infantry. Unfortunately, the reaction times were not recorded for individual symbols (see Procedure section); therefore, this explanation could not be evaluated. A third explanation for finding no perceptual advantage for the iconic symbols is that only outline silhouettes--rather than filled-in silhouettes (see Figure 1)--were utilized; suggestions have been made that the latter might be perceived more accurately and more quickly (Chainova et al., 1974; Yoeli and Loon, 1972). A final possibility is that the use of mirror images of the three basic unit symbols to portray enemy versus friendly forces may have contributed to a slowed processing of the iconic forms in comparison to the conventional forms. That is, with the iconic symbols, participants had to be aware of six distinct symbol shapes which were required to represent the three types of units because the enemy units were portrayed as facing the friendly units (see Figure 4); whereas with the conventional symbols, only three different basic shapes were necessary since directionality was not portrayed in the basic symbol shapes (see Figure 2).

Portrayal of Unit Attributes

The present results also illustrate that the portrayal of unit attributes, such as unit strength or firepower reach, by adding symbol features, interferes with the processing of unit-type information. In four tasks (identification, search, comparison, pattern recognition), reaction times were significantly longer for answering questions referring to the type of units portrayed when a symbol-design feature (perimeter density or vector projection) was varied in the displays to represent a unit attribute. Thus, there is a trade-off between representing essential information in a display (Sidorsky, 1977) and minimizing clutter (Hanby and Shaw, 1969; Simonsen, 1977). However, in three of these four task analyses, the use of the vector-projection design feature was found to slow performance on unit-type questions to a lesser extent than did the use of the perimeter-density design feature. This result suggests that, even though greater display clutter retards certain types of information processing, the degree of interference can be minimized through the careful choice of design features. Apparently, a vector projection does not alter the perceptability and discriminability of the core unit symbols as does the perimeter-density design feature.

In addition, the results suggest that an appropiate choice of design feature is not simply a function of which features produce less display clutter; but rather, as illustrated in the reaction time data for the unit-attribute questions, certain design features appear to be more compatible with certain military concepts than others (Bersh, et al., 1978). Specifically, the portrayal of firepower reach with vector projections and unit strength with perimeter-density coding led to faster reaction times than did the reverse pairing. Perhaps the vector projections appear as gun barrels or bullets "extending" from a unit, and in a

sense this design feature is in itself somewhat iconic. In contrast, perimeter-density coding, an alteration of the core unit form, may be more compatible with unit attributes describing the internal composition of the unit, such as unit strength.

Threat Value Assessment

The results for the symbol integration or threat value assessment task provide some interesting implications. First of all, the high level of accuracy on this task--irrespective of whether conventional or iconic symbols were used--suggests that participants can chunk and integrate symbolic information together rapidly to make meaningful, and relatively accurate assessments about a given symbol configuration. This finding is consistent with the results of Badre (1979), who studied tactical-symbol chunking using a memory paradigm, as well as with the conclusion of Wheatley (1977) that abstract information such as threat can be judged reliably when represented in multi-dimensional form. Secondly, the improvement in performance when fewer symbol dimensions needed to be integrated suggests that the reduction of unnecessary detail and display clutter (Simonsen, 1977) may enhance anlaytical judgments. In fact, one way of achieving such reductions in tactical displays might be through the use of selective (adaptive) call up of only critical symbols (units) or symbol dimensions (Channon, 1976).

SUMMARY

In summary, the present experiment illustrates an approach to the evaluation of candidate tactical display symbologies based on human performance criteria. In this approach, performance is assessed in relation to fundamental behavioral processes thought to underlie the routine

use of complex battlefield displays. The results, within the constraints of the experiment, suggest that:

(1) Iconic symbols (at least of the form studied--i.e., blocked, hollow iconic symbols) are not necessarily identified faster than conventional symbols, and such iconic symbols may not be conducive to locating certain embedded patterns of symbols rapidly.

(2) The portrayal of supplementary information about units through the use of peripheral design features slows the processing of unit-type information, although vector projections produce less interference than perimeter-density codings. Furthermore, vector projection is more compatible with the portrayal of firepower reach, and perimeter-density coding is more compatible with the portrayal of unit strength, rather than vice versa.

(3) Analytical assessments involving the integration of many symbols can be made more accurate when fewer symbol dimensions need to be processed.

These findings have important implications for the design of improved and new tactical symbologies for the future--especially if they are supported by additional experiments in which a greater number of different symbols are used, and/or instances of symbol overlap are allowed.

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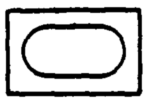
APPENDIX A

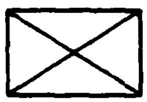
SAMPLE INSTRUCTION BOOKLET
FOR LEARNING A SYMBOLIC LANGUAGE

LEARNING THE SYMBOLS

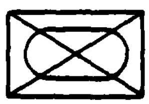
On the battlefield displays that you will see, some basic symbols are used to represent different types of military units. You must learn what these symbols represent so that you can answer questions about them. The types of military units that we will use are armor (a group of tanks), infantry (a group of soldiers on foot), and mechanized infantry (a group of soldiers transported in vehicles). The three basic symbols used to represent these types of units are as follows:



armor unit



infantry unit



mechanized infantry unit

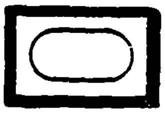
Please make sure that you can give the names of these symbols from memory.

In addition, on some displays, we will represent certain characteristics of the military units. The characteristics include resource strength (what percentage of a unit's typical resources, such as weapons, ammunition, supplies, etc. are currently available for use--100%, 50%, or 0%), and firepower reach (how far, at present, can a unit shoot with its weapons--60 kilometers, 40 kilometers, or 20 kilometers). These characteristics of the military units are portrayed as follows:

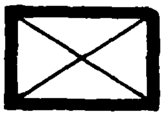
Strength

Strength is portrayed by blackening in a number of sides of the symbol representing a unit. The number of sides blackened in corresponds to different levels of strength as follows.

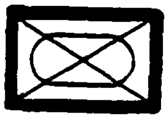
100% - If all four sides of a symbol are blackened in, that means that the unit is at 100% of its original strength (weapons, ammunition, supplies, etc.).



armor unit - 100% strength

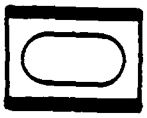


infantry unit - 100% strength

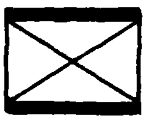


mechanized infantry unit - 100% strength

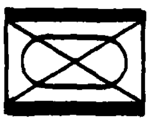
50% - If two sides (the top and the bottom) are blackened in, that means that the unit is at 50% strength.



armor unit - 50% strength



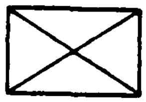
infantry unit - 50% strength



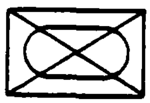
mechanized infantry unit - 50% strength

0% - If no sides are blackened in, that means that the unit is at 0% strength.

armor unit - 0% strength



infantry unit - 0% strength

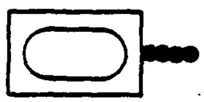


mechanized infantry unit - 0% strength

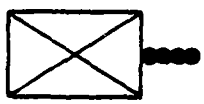
Reach

Reach is portrayed by a chain of four circles sticking out from a symbol in the direction of the battlefield line separating the enemy and friendly forces. These circles will either all be "hollow" (oooo), two will be blackened in (●●oo), or all four circles will be blackened in (●●●●). The number of circles filled in corresponds to different levels of reach as follows.

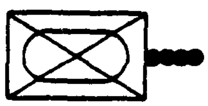
60 KM - If all circles are filled in, that means that the unit has a 60 kilometer reach capability, which is equal to six squares on the map.



armor unit - 60 KM reach

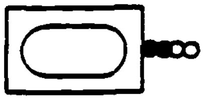


infantry unit - 60 KM reach

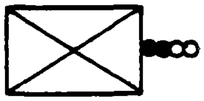


mechanized infantry unit - 60 KM reach

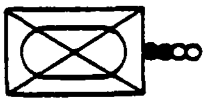
40 KM - If half of the circles (the first two nearest the symbol) are blackened in, that means that the unit has a 40 kilometer, or four square, reach capability.



armor unit - 40 KM reach

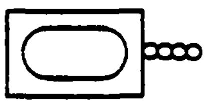


infantry unit - 40 KM reach

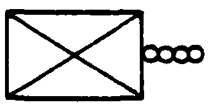


mechanized infantry unit -
40 KM reach

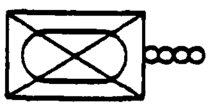
20 KM - If none of the circles are blackened in, that means that the unit has a 20 kilometer, or two square, reach capability.



armor unit - 20 KM reach



infantry unit - 20 KM reach



mechanized infantry unit -
20 KM reach

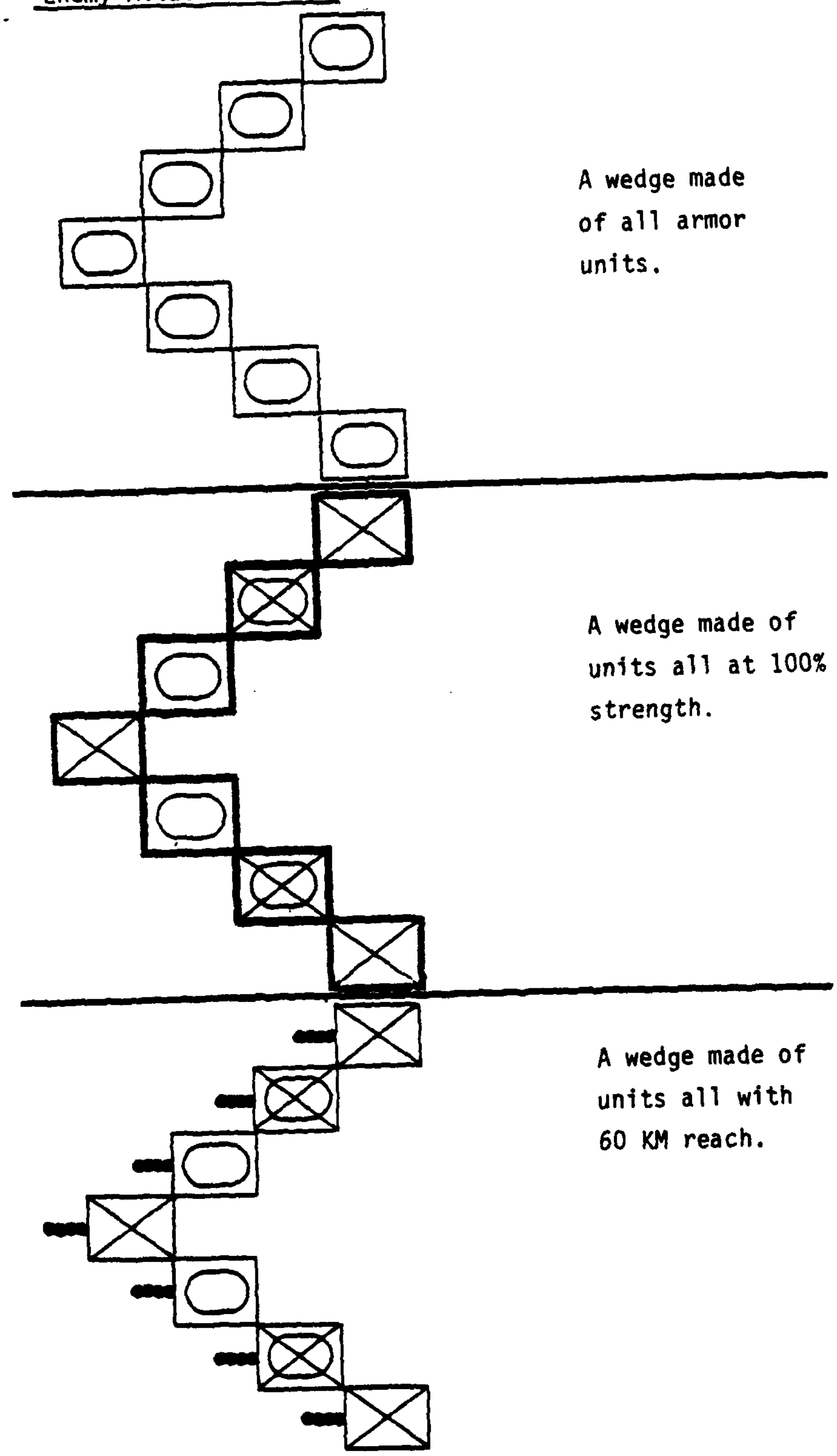
Attack Patterns

Finally, you will be asked to find an "attack" pattern of symbols in either the friendly or enemy side. For purposes of this study, we will define an attack pattern as a wedge shape. Friendly attack patterns face to the right (>), enemy attack patterns face to the left (<). An attack pattern is composed of 7 units (3 units on each side of the unit "in the lead"). The valid attack patterns are:

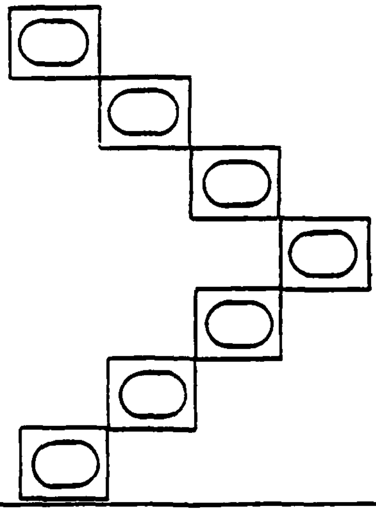
> 7 armor units (regardless of their strength or reach)
> 7 units of 100% strength (regardless of the types of units)
> 7 units with 60KM reach (regardless of the types of units)

Attack patterns defined by the strength (100%) or reach (60KM) may contain a mixture of unit types <u>or</u> they may be composed of one type of unit (such as infantry). The three legitimate attack formations facing left and right are shown on the following two pages.

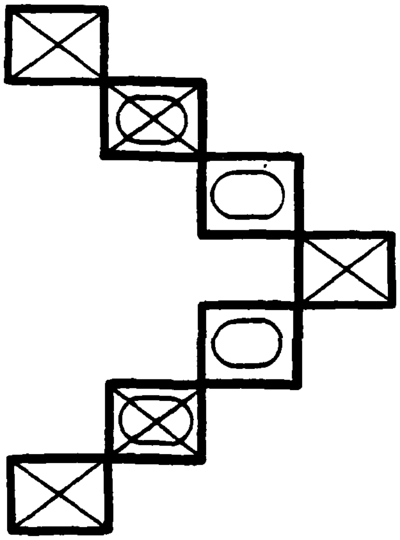
Enemy Attack Pattern



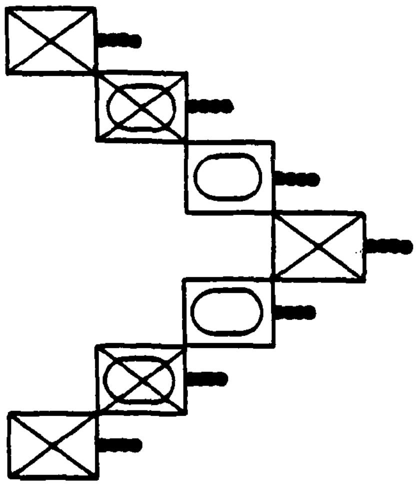
Friendly Attack Pattern



A wedge made of all armor units. (regardless of strength or reach)



A wedge made of units all at 100% strength. (regardless of the type or types of units)



A wedge made of units all with 60 KM reach. (regardless of the type or types of units)

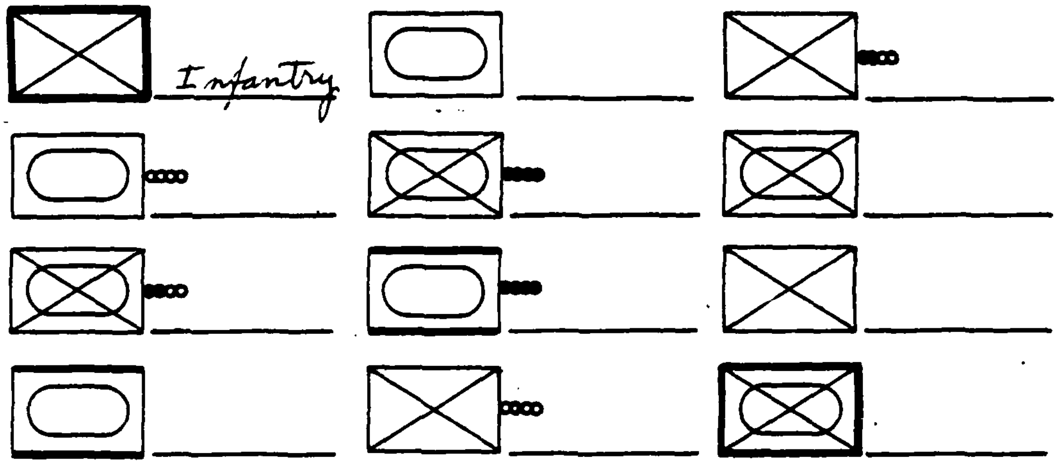
APPENDIX B

SAMPLE PRETEST

PRE-TEST

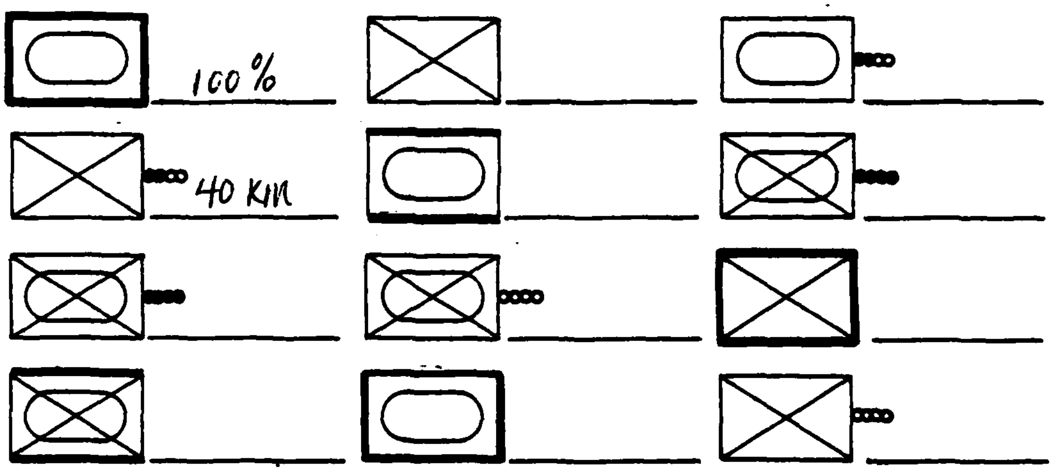
(1) <u>Unit Identification</u>

Write the names of the following units in the corresponding blanks. Write only the unit names (the first one is filled in for you).



(2) <u>Reach and Strength Assessment</u>

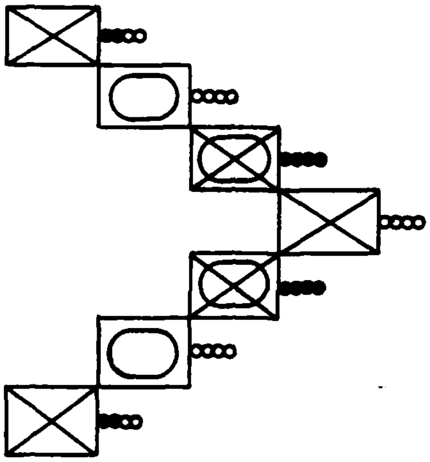
Write the reach <u>or</u> strength of each of the following units in the corresponding blanks. Write only the reach in kilometers <u>or</u> the strength in percentage terms for each unit (the first two are filled in for you).



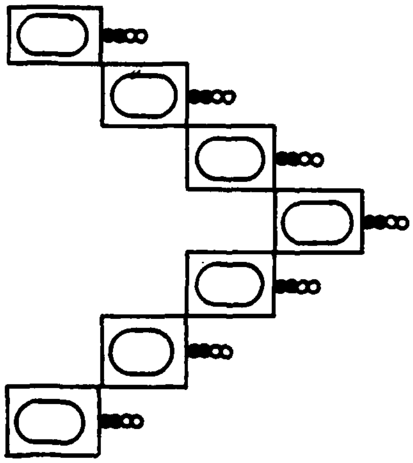
(3) <u>Attack-Pattern Identification</u>

Put a check next to any of the following patterns that are acceptable, legitimate attack patterns, as defined in the instructions.

a



b



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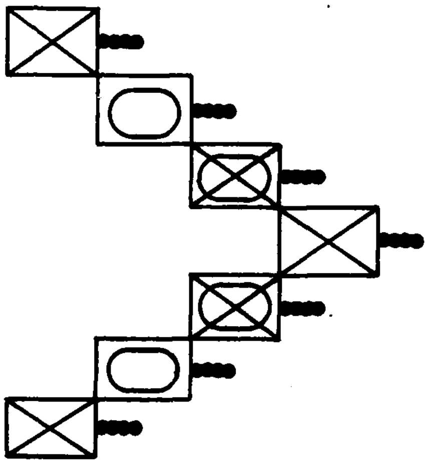

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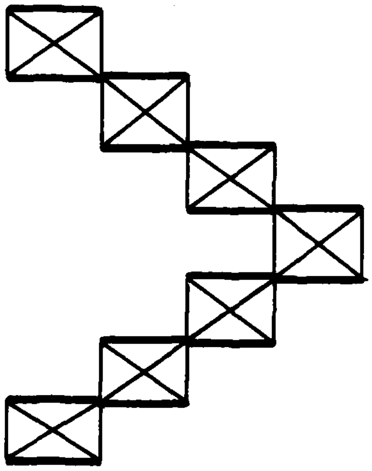

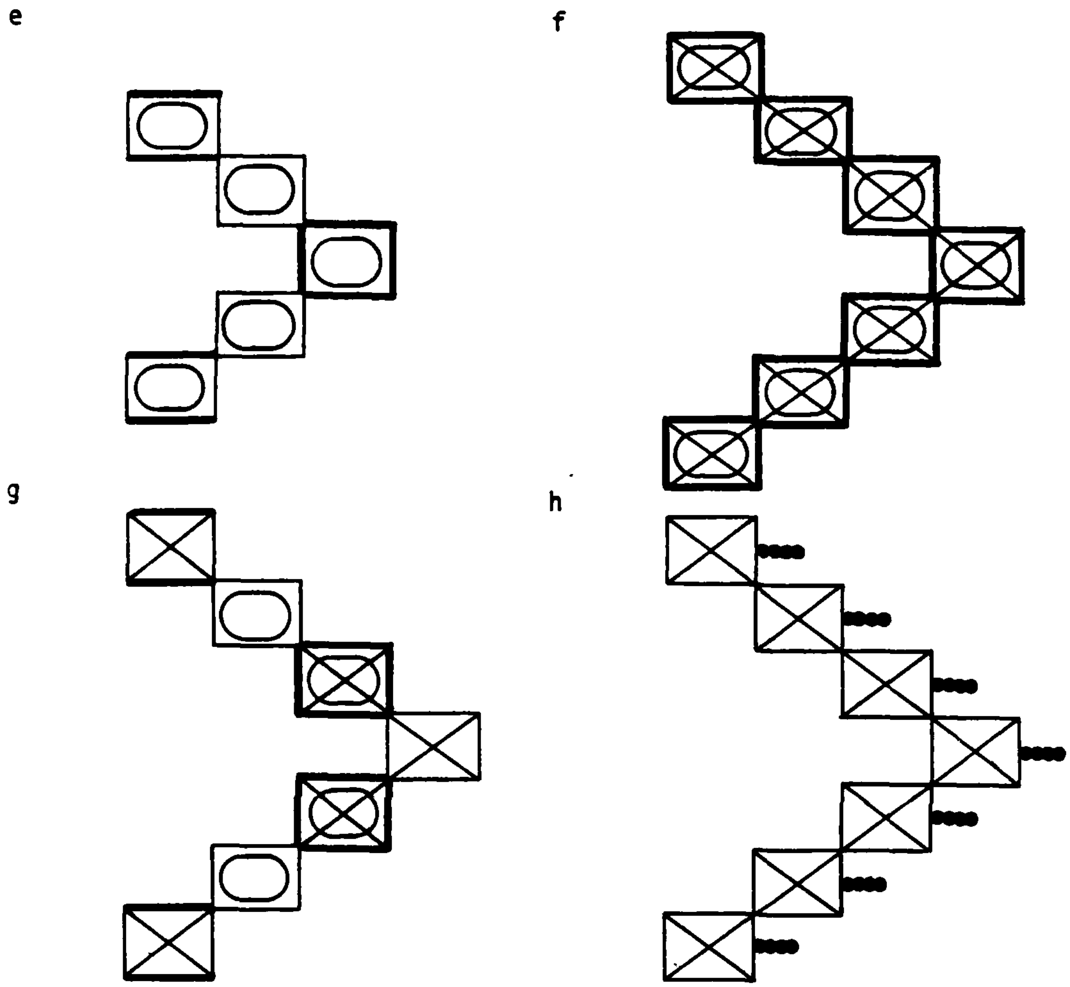
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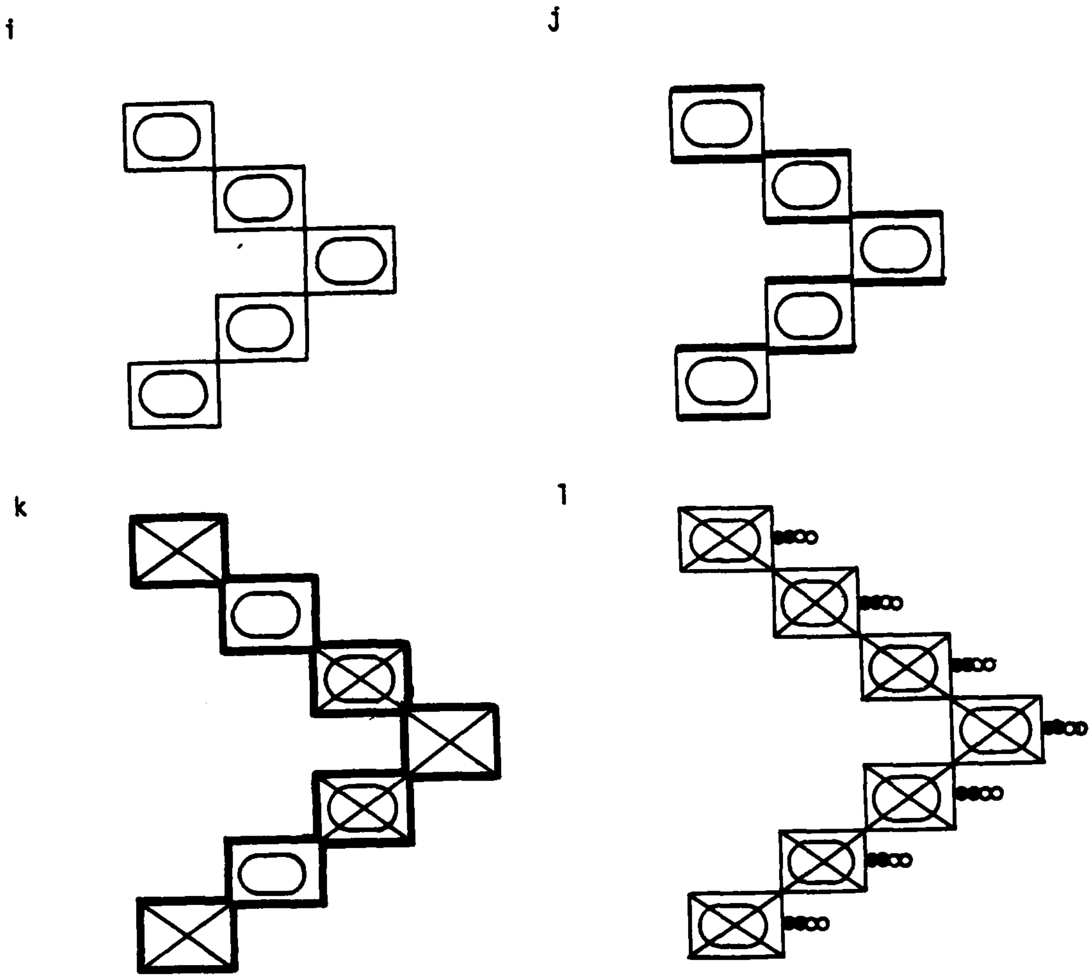
i
j
k
l

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